AD-A185 439 FABRICATE CALIBRATE AND TEST A DOSIMETER FOR INTEGRATION INTO THE CRRES (..(U) PANAMETRICS INC WALTHAM MASS P R MOREL ET AL. JUN 87 SCIENTIFIC-4 1/1

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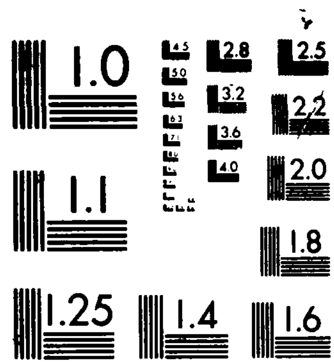

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FABRICATE, CALIBRATE and TEST A DOSIMETER FOR INTEGRATION INTO THE CRRES SATELLITE

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June 1987

SCIENTIFIC REPORT NO. 4

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-87-0232	2. GOVT ACCESSION NO. AD-A185 439	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Fabricate, Calibrate and Test a Dosimeter for Integration into the CRRES Satellite		5. TYPE OF REPORT & PERIOD COVERED Scientific Report No. 4
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Paul R. Morel, Ram Cohen, Frederick A. Hanser, Bach Sellers		8. CONTRACT OR GRANT NUMBER(s) F19628-82-C-0090
9. PERFORMING ORGANIZATION NAME AND ADDRESS Panametrics, Inc. 221 Crescent Street Waltham, MA 02254		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 760112AK
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, MA 01731 Contract Monitor: Lt. Marilyn Oberhardt PHP		12. REPORT DATE June 1987
		13. NUMBER OF PAGES 32
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dosimeter	Particle Fluxes
Electron Dose	Nuclear Stars
Proton Dose	Space Radiation Dosimeter
Space Radiation	CRRES Spacecraft

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A space-radiation Dosimeter has been fabricated, calibrated, and tested, and will be integrated into the CRRES spacecraft. This Dosimeter is essentially identical to that previously designed, fabricated, calibrated, tested and integrated into the DMSP F7 satellite. These dosimeters are primarily designed to measure the dose from electrons of greater than 1 MeV to greater than 10 MeV in four channels. Each channel has a different thickness aluminum dome. The solid state detector outputs are processed to provide

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20. Abstract (Continued)

the dose from electrons (low energy loss), the dose from protons (high energy loss), the flux from electrons, the flux of protons, and the rate of high energy loss nuclear star events. The dosimeter also has a calibration mode in which the alpha particles from a weak source behind each detector are used to check for total detector depletion and proper operation of the electronics.

A high energy electron Fluxmeter to measure electrons from 1-10 MeV in ten differential channels will also be integrated into the CRRES spacecraft. The Fluxmeter will be modified to provide a low voltage continuous bias to the solid state detectors to reduce the possibility of detector degradation in storage and in vacuum. The Fluxmeter will be retested as necessary, and then be delivered and integrated into the CRRES spacecraft.

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1. INTRODUCTION

The increasing use of complex solid state electronic devices in the space radiation environment makes it important to have reliable data on the radiation doses these devices will receive behind various thicknesses of shielding. As part of the effort to obtain this data a Dosimeter was designed, fabricated, calibrated, and integrated into the payload of a Defense Meteorological Satellite Program (DMSP) satellite by Panametrics, Inc., for the Air Force Geophysics Laboratory, under contract number F19628-78-C-0247. The current contract, F19628-82-C-0090, is for the fabrication and calibration of a second, essentially identical, Dosimeter and its integration into the Combined Release and Radiation Effects Satellite (CRRES). These Dosimeters measure the accumulated radiation dose in silicon solid state detectors behind four different thicknesses of aluminum shielding. The current contract also covers the integration into the CRRES spacecraft and launch support of the Fluxmeter, a high energy electron spectrometer built by Panametrics for AFGL under contract number F19628-79-C-1075.

The objectives of the current contract can be summarized as follows:

a. Participate in the integration and launch tests of the F7 DMSP satellite in order to determine proper interfacing, of the Dosimeter, with other satellite components and proper operation prior to, and immediately after launch.

b. Study the DMSP Dosimeter calibration and early flight data to determine the optimum method of producing omnidirectional spectra from the electron and proton data and determine the dose calibrations for small, large and very large energy deposition levels.

c. Fabricate, test, calibrate and deliver a radiation Dosimeter, essentially identical to the DMSP Dosimeter, for integration into the CRRES satellite.

d. Participate in the integration and launch tests of the CRRES satellite in order to determine proper interfacing, of the Dosimeter and Fluxmeter, with other satellite components and proper operation prior to, and immediately after launch.

e. Analyze calibration and early flight data of the CRRES Dosimeter to determine the performance of the Dosimeter in space flight and the quality of flight data.

The work carried out during the first (1 September 1982 to 31 August 1983), second (1 September 1983 to 31 August 1984) and third (1 September 1984 to 31 August 1985) years of this contract has been reported in Refs. 1.1, 1.2, and 1.3, respectively. This report covers the work carried out during the fourth year (1 September 1985 to 31 August 1986). A brief description of the Dosimeters, and a summary of their specifications, are given in Section 2. Section 2.1 deals specifically with the DMSP Dosimeter while Section 2.2 deals with the CRRES Dosimeter. The progress to date is summarized in Section 3. Section 3.1 covers the DMSP integration and launch support (item a, above) while Section 3.2 covers the DMSP calibration and flight data analysis (item b). Section 3.3 covers the CRRES Dosimeter fabrication, testing and calibration (item c) and Section 3.4 covers the CRRES Dosimeter and Fluxmeter integration and launch support (item d). Section 3.3.2 contains a short description of the calibration work performed with the CRRES Dosimeter to date. Most of the effort on item e will occur after more complete calibration of the Dosimeter, and especially after the launch of the CRRES spacecraft.

2. DOSIMETER DESCRIPTIONS AND SPECIFICATIONS

2.1 Description and Specifications of the DMSP Dosimeter

The DMSP Dosimeter was designed, fabricated, tested and calibrated by Panametrics, Inc., for the Air Force Geophysics Laboratory, under contract number F19628-78-C-0247. This instrument's specifications are outlined in Table 2.1. It should be noted that the unit was specifically designed to interface with the DMSP spacecraft and its Operational Linescan System (OLS). The DC to DC converter design, in particular, took advantage of the closely regulated DMSP power bus (28.0 $\pm$ 0.5 VDC) which eliminates the requirement for further line voltage regulation and results in reduced power consumption, weight and volume. The data registers are also optimally scaled for the approximately circular 800 km DMSP orbit. A detailed description of the DMSP Dosimeter is presented in Ref. 2.1. The design is, of course, adaptable to other spacecraft and/or orbits.

An isometric view of the DMSP Dosimeter is shown in Fig. 2.1. The 4 domes house the solid state detectors. The dome thickness increases with the size, resulting in four different incident particle energy thresholds. The instrument interfaces to the DMSP spacecraft through P1 and to the OLS through P2. J12 is a test connector which is capped during flight. A cutaway isometric view, showing the various printed circuit boards and the details of one detector, is given in Fig. 2.2. The four charge sensitive preamplifier test input connectors, shown in Fig. 2.2, are also capped for flight.

The Dosimeter separates the total radiation dose into that from electrons (50 keV to 1 MeV energy deposits) and protons (1 to 10 MeV energy deposits). The four aluminum shields provide energy thresholds (range thickness values) of 1, 2.5, 5, and 10 MeV for electrons, and 20, 35, 51, and 75 MeV for protons. The primary

Table 2.1

Specifications for the DMSP Dosimeter

Sensors	4 Planar silicon S.S.D. with aluminum shields.
Field of View	2 pi Steradians
Data Fields	3 deposited energy ranges and 2 dose energy ranges per sensor, resulting in 5 data fields: 1 Electron Dose 1 Electron Flux 1 Proton Dose 1 Proton Flux 1 Nuclear Star Flux
Output Format	36 Bits serial, read out once per second. Each readout is internally multiplexed and must be interpreted in the context of a 64 readout data frame.
Command Requirements	On/Off, Reset, and Calibrate
Size	8" H x 4.5" W x 5.5" D excluding Domes, Connectors, and Mounting Tabs
Weight	10.0 lbs
Power	7.0 W @ 28 V $\pm$ 0.5 V DC
Temperature Range	-10^{o}C to 40^{o}C
Max Accumulated Dose before recycling	$\doteq 10^4$ rads (Si) Electrons $\doteq 10^3$ rads (Si) Protons
Max Flux before overflow	$\doteq 10^6$ electrons/(cm^2-sec) above 1 MeV $\doteq 10^4$ proton/(cm^2-sec) above 20 MeV
Effective Area (For omnidirectional flux)	0.013 cm^2 (Dome 1), 0.25 cm^2 (Dome 2, 3, and 4)

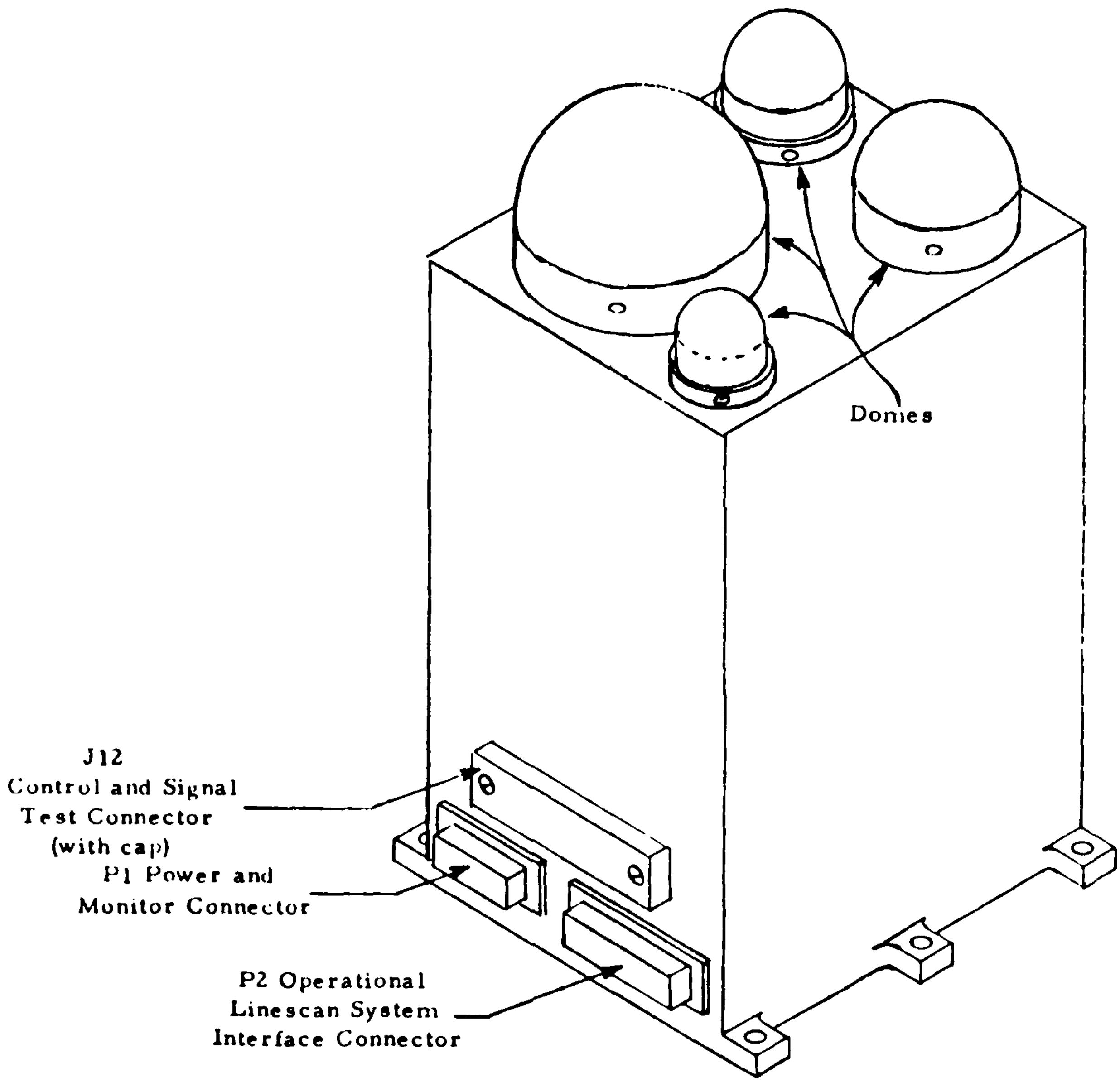

Fig. 2.1 Isometric View of the DMSP Dosimeter

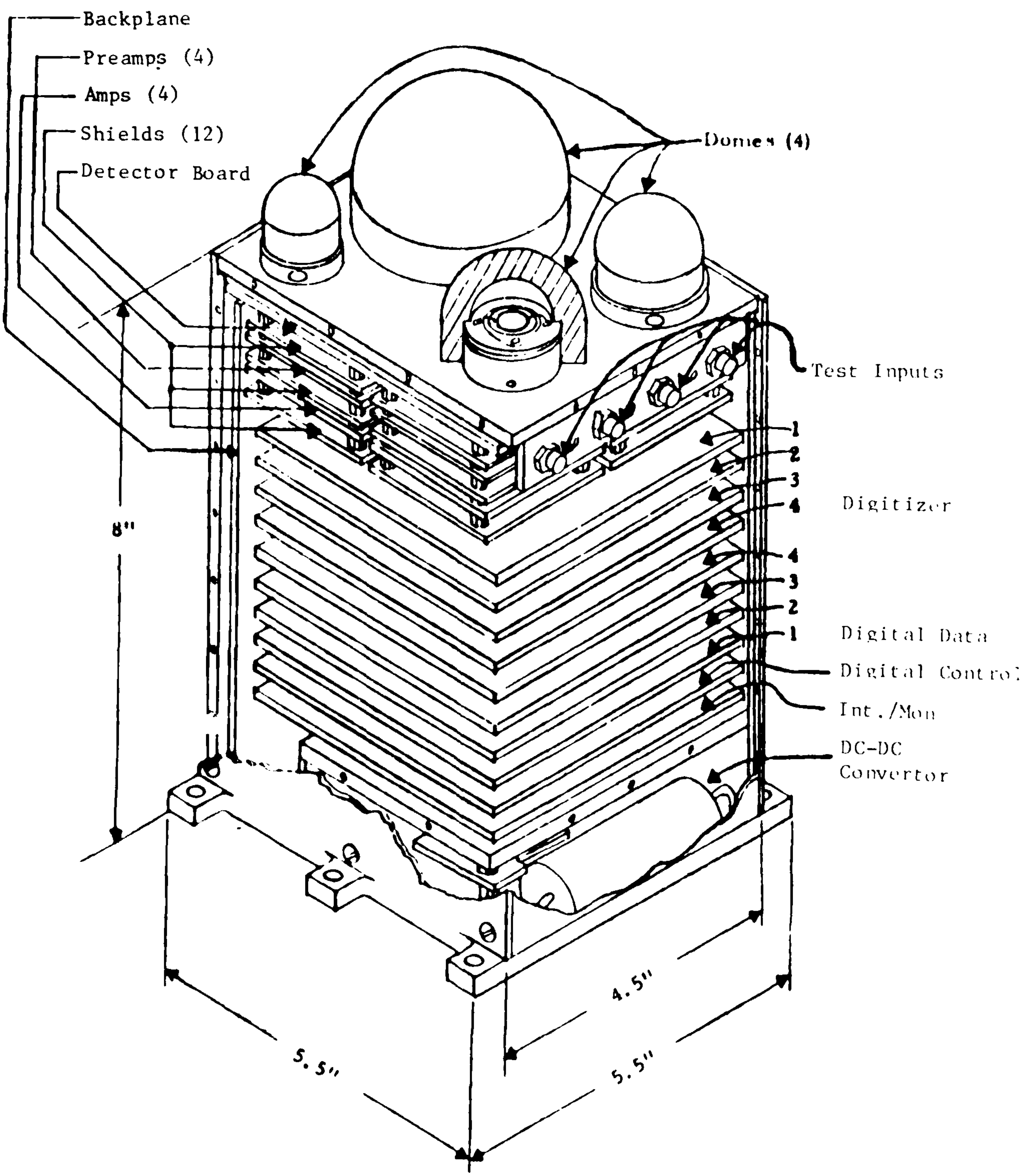

Fig. 2.2 Cutaway Isometric View of the DMSP Dosimeter

measurement, and that most accurately calibrated, is the accumulated dose. Omnidirectional electron and proton fluxes are also measured, and data on the detailed response of each channel to energy and angle for electrons and protons have been obtained. There is also a high energy loss event channel which counts the rare nuclear star events caused by high energy protons, and the low flux of high energy high-Z cosmic rays. Information on these high energy loss events is important, since they can cause logic upsets or memory bit loss in some types of low power microcircuits.

The DMSP Dosimeter was extensively calibrated by use of protons from the Harvard Cyclotron, and electrons from the AFGL/RADC Linac. The 160 MeV proton beam at the Harvard cyclotron was passed through two beam-spreading absorbers to provide a maximum energy of 144 MeV at the Dosimeter. Additional absorbers were used to reduce the energy to as low as 17 MeV. Data were taken for incident directions (relative to the Dcme plane normal) from 0^{o} to 180^{o} (rear entry). The electron data taken at the AFGL Linac covered the range of 0.9 to 18.4 MeV. The nominal electron energies were calibrated against known gamma-ray energies with a 1 inch thick BGO crystal, so the corrected energies should be accurate to better than 5%. The Dosimeter was also calibrated extensively using gamma-ray and beta sources, with this being the primary method of calibrating the dose channel responses. The electron and proton beam calibrations are primarily to verify proper unit operation, and to calibrate the flux channels in terms of the incident particle fluxes.

The final parameters for the four channels of the DMSP Dosimeter are given in Table 2.2. These values are based on the final dose prescaler values and the calibrated detector responses. The electron channels are based on detector energy losses of 50 keV to 1 MeV, and the proton channels on 1 MeV to 10 MeV. In the calibration mode the electron channel becomes a lower loss range of 1 to 3 MeV and the proton channel an upper loss range of 3 to 10 MeV. This mode is used to check total depletion of the detectors by looking at the alpha source which irradiates the rear of the detectors.

The DMSP Dosimeter underwent a complete acceptance test sequence, in accord with a Test and Acceptance Plan approved by AFGL. Vibration testing was carried out at the AFGL test facility. Thermal and vacuum testing were done in house at Panametrics. Initial spacecraft integration tests took place at the Westinghouse facility in Baltimore, Maryland (the OLS contractor) and the Dosimeter was shipped to RCA Astroelectronics Division (the spacecraft contractor) on June 2, 1981 for integration into the DMSP F-7 spacecraft.

Table 2.2

Final Parameters for the DMSP Dosimeter

Item	Ch 1 Value	Ch 2 Value	Ch 3 Value	Ch 4 Value
Al Shield (g/cm^2)	0.55	1.55	3.05	5.91
Electron Threshold (MeV)#	1.0	2.5	5.0	10.
Proton Threshold (MeV)#	20	35	51	75
Star Threshold (MeV)#	40	40	75	40
Detector Area (cm^2)	0.051	1.00	1.00	1.00
Max elect. flux (cm^{-2} sec^{-1})*	2.41×10^6	1.23×10^5	1.23×10^5	1.23×10^5
Max proton flux (cm^{-2} sec^{-1})*	1.95×10^4	922	922	922
Elect. dose prescaler	8192	16384	4096	4096
Proton dose prescaler	64	1024	256	256
Max. elect. dose (RADS)**	1.27×10^4	1.29×10^3	323	323
Max. proton dose (RADS)**	990	808	202	202
Electron calibration constant (RADS/output dose count)	1.78×10^{-3}	1.81×10^{-4}	4.30×10^{-5}	4.85×10^{-5}
Proton calibration constant (RADS/output dose count)	1.36×10^{-4}	1.11×10^{-4}	2.90×10^{-5}	2.92×10^{-5}

*Flux value above which the flux count will overflow. Only the flux readouts are affected, as dose is still accumulated correctly.

**Dose at which the counters overflow and recycle to zero. Dose accumulation continues correctly.

#The electron and proton thresholds are the nominal particle energy to just penetrate the dome shields; the star thresholds refer to energy deposits in the detectors.

2.2 Description and Specifications of the CRRES Dosimeter

The modified specifications for the CRRES Dosimeter, which was fabricated, tested and calibrated by Panametrics, Inc. for the Air Force Geophysics Laboratory, are outlined in Table 2.3. These specifications are updated for Contract modifications from Amendment #11, 4/23/86, and are identical to those of the DMSP Dosimeter except for the following two items:

a) The CRRES power bus regulation is 28.0 $\pm$ 4 VDC, as opposed to the 28.0 $\pm$ 0.5 VDC DMSP power bus. This necessitates the addition of a line voltage regulator, and it results in a slight increase in the instrument's weight and power requirements, which are reflected in Table 2.3. The actual average and maximum power requirements for the completed CRRES Dosimeter are also listed.

b) The peak high energy proton flux at the specified CRRES orbit is about a factor of 10 higher than that at the DMSP orbit. This necessitates the use of smaller detectors for D1, D2 and D3, and the addition of a prescaler in the highest energy proton flux channel to prevent counter overflow. This modification has no impact on the instrument's volume, negligible impact on power requirement and a very slight impact on its weight.

The mechanical configuration of the CRRES Dosimeter is identical to that of the DMSP Dosimeter, as shown in Figures 2.1 and 2.2.

Table 2.3

Specifications for the Modified CRRES Dosimeter

Sensors	4 Planar silicon S.S.D. with aluminum shields.
Field of View	2 pi Steradians
Data Fields	3 deposited energy ranges and 2 dose energy ranges per sensor, resulting in 5 data fields: 1 Electron Dose 1 Electron Flux 1 Proton Dose 1 Proton Flux 1 Nuclear Star Flux
Output Format	36 Bits serial, read out once per second. Each readout is internally multiplexed and must be interpreted in the context of a 64 readout data frame. (The CRRES spacecraft actually reads 40 bits - the 36 data bits followed by 4 logical zeroes.)
Command Requirements	On/Off, Reset, and Calibrate
Size	8" H x 4.5" W x 5.5" D excluding Domes, Connectors, and Mounting Tabs
Weight	10.0 lbs
Power	7.5 W @ 28 V $\pm$ 4.0 V DC (Actual = 6.3 W average, 6.9 W maximum)
Temperature Range	$-10^{o}C$ to $40^{o}C$
Max Accumulated Dose before recycling	$\doteq 10^4$ rads (Si) Electrons $\doteq 10^3$ rads (Si) Protons
Max Flux before overflow	$\doteq 10^8$ electrons/(cm^2-sec) above 1 MeV $\doteq 10^6$ proton/(cm^2-sec) above 20 MeV
Effective Area (For omnidirectional flux)	0.0020 cm^2 (Dome 1), 0.013 cm^2 (Domes 2 and 3), 0.25 cm^2 (Dome 4)

3. PROGRESS TO DATE

3.1 DMSP Dosimeter Integration and Launch Support

It should be noted that the DMSP instruments are referred to as "special sensors" and that the Dosimeter is designated the "SSJ*" special sensor.

Integration and testing of the DMSP F-7 spacecraft was completed in November 1983 and the spacecraft was launched, with the SSJ* Dosimeter on board, late that month. The SSJ* Dosimeter was first turned on in Rev 77 on 23 November 1983 at 1625 UT. At turn-on the temperature was +11°C, which decreased to +8°C during the first orbit cycle, but climbed to +46°C at the start of Rev 84. The Dosimeter was thus turned off at 0430 UT on 24 November 1983. The Dosimeter was turned on again at 0850 UT on 25 November 1983, in Rev 101. The temperature started at +17°C and increased over the next several orbits, reaching a plateau of 50°C ± 3°C by Rev 121 (1830 UT on 26 November), with the ± 3°C being the sun/shadow cycling for each orbit. The temperature variations for several orbits (Revs) were shown in Figures 3.1 to 3.3 of Ref. 1.3.

Analysis of Normal Mode and Calibration Mode data indicated completely proper operation of the Dosimeter, both at the low temperature after turn-on, and at the maximum temperature of 53°C. The Am^{-241} calibration source data during periods of low ambient background indicated the detectors were still totally depleted. Thus the dose and flux data were all valid using the pre-launch calibrations.

As discussed in Ref. 1.3, the predicted in-orbit temperature for the Dosimeter was +26°C for the minimum 30° solar zenith angle of the DMSP-F7 orbit. The originally specified operating temperature range for the SSJ* was -10°C to +40°C, so the actual operating temperature exceeded this by +13°C. Since the SSJ* Dosimeter was operating properly, the operating specifications given to GWC (Global Weather Central) were changed to: 1) notify AFGL/Panametrics if the temperature exceeds +55°C; and 2) turn the SSJ* off if the temperature exceeds +60°C.

Dosimeter temperature data obtained for 15 February 1984 show a temperature cycle of 45.8°C to 51.4°C, slightly lower than at the end of November 1983. The DMSP Dosimeter temperature peaked during November-December 1984, reaching a maximum of 55.2°C. A plot of five (5) orbits of temperature data for 2 December 1984 were shown in Fig. 3.4 of Ref. 1.3. By late February 1985 the maximum temperature had decreased to 52.9°C.

In mid-November 1984, a number of phone calls were received from Ben Pope of Westinghouse about the temperature rise and its expected peaking in November. A number of Cal Mode print-outs from the AWS were requested and have been analyzed. On Friday, 23 November 1984, F. Hanser of Panametrics was notified by the AWS that the Dosimeter had reached 55.2°C, past the notification level of 55°C. Dosimeter operation was continued, with shut-off remaining at 60°C. Additional Cal Mode data and two full orbits of regular mode data were obtained from Ben Pope. Analysis of these data show that the D4 electron channel reaches a peak noise count-rate of about 500/sec at the maximum temperature of about 55°C, and falls to the background level of about 10 sec/at 48.5°C. The Cal Mode data show that even at the peak temperature of 55°C all the detectors are fully depleted and all gains and thresholds are correct. The Dosimeter is thus operating properly at 55°C after one year in orbit at about a 50°C average temperature, with only D4 showing an increase in noise at 55°C. This was discussed with AFGL personnel and it was recommended that the Dosimeter be left on continuously, since on/off cycling to lower the temperature was likely to be more stressful.

The background count-rate in the D4 electron channel is not excessive and does not produce a significant dead time (less than 0.1%). The D4 electron dose will have to be corrected for the noise addition. None of the other channels has a significant contribution from noise. This indicates that the Dosimeter should operate reliably for at least one more year, with the D4 electron channel noise probably being higher in November 1985, at the next temperature maximum, although it is still likely to provide usable data. The Dosimeter operation in orbit is excellent considering that it is operating at 10 to 15°C above the specification maximum of 40°C.

A VAR (Vehicle Anomaly Report) was opened by GWC to at least document, and possibly determine the cause of, the SSJ* temperature problem. The SSJ* is mounted to the DMSP satellite with electrical isolation at the base, and a thermal insulating blanket around the sides. Most of the heat radiation thus takes place through teflon tape on the top surface around the detector domes. The high temperature could thus be the result of contamination of the tape surface, reducing its emissivity, or of the tape partially pulling away from the surface. During the various integration, thermal vacuum, etc., tests at RCA, the Dosimeter temperature never exceeded +30°C, although this is only for about 4 hours of operation. The VAR was closed in August 1984, with the conclusion that it is most likely a thermal design error. The Dosimeter power consumption was verified to be 6 W, as specified, while the base plane temperature is about 10°C. The thermal design assumed a thermal conductivity between the Dosimeter and the base plane of 0.22 W/°C, which is apparently too high as this would put the Dosimeter at about 37°C (which is close to the +40°C maximum specifications for the Dosimeter!). Since the Dosimeter is electrically isolated from the spacecraft at its mounting points, this probably contributed to the problem of lower thermal conductivity to the spacecraft.

A check of test records at Panametrics shows that in May 1982, when the Dosimeter was returned to Panametrics for a grounding modification and check-out, the Dosimeter was given a two-week test in vacuum where it ran at about 50°C. These test data show proper Dosimeter operation at that temperature, so the in-orbit 50°C ± 3°C operation has actually been tested before launch (for a relatively short-term period). The Dosimeter electronics have been tested to much higher temperatures, so the detectors are the only potential problem at high temperature. The detectors are photodiodes operated as particle detectors at total depletion. At high temperatures the leakage current increases, leading to eventual partial depletion, and the noise level increases, leading to excessive noise in the electron channels. At +50°C the detectors are still totally depleted, and noise is still not noticeable at the 50 keV electron threshold.

Calibration cycle data were received from the AWS/Omaha for November 4, 1985, and were analyzed in more detail and presented at a meeting with AFGL personnel. The Nov. - Dec. 1985 period of maximum Dosimeter temperature resulted in peak temperatures of about 56°C, the highest experienced thus far. At the peak temperatures both the Dome 3 and Dome 4 electron channels show noise counts. Dome 4 showed noise counts during the Nov. - Dec. 1984 temperature peak, but the 1985 count rates are higher, and Dome 3 now shows significant counts. The 1985 temperature peak is slightly higher than the 1984 peak (1-2°C), so the increased noise counts may be primarily a temperature effect. However, there may also be an increased noise effect because of detector deterioration at the high temperature of the DMSP/F7 Dosimeter.

The DMSP/F7 Dosimeter has now been operating in orbit for more than 2 1/2 years at 45 to 55°C, well above the specified maximum of +40°C. Most of the data are still reliable, so the instrument operation is remarkably good, considering the extreme out-of-tolerance operating environment. In general, the Dome 3 and Dome 4 electron channels primarily measure the bremsstrahlung from lower energy electrons, so the noise counts in these channels do not affect important data. It is expected that the DMSP/F7 Dosimeter will provide a significant amount of reliable data as long as the DMSP/F7 spacecraft is operating.

3.2 DMSP Dosimeter Flight Data Analysis

The routine analysis of the DMSP F7 Dosimeter flight data at AFGL is basically in operation. The algorithms for obtaining the dose and flux increments from the DMSP Dosimeter data were completed and have been verified with checks against actual data. The final procedure corrects the four-second dose increments for ripple counter overflow. A check against South Atlantic Anomaly (SAA) data shows that the summed dose increments equal the actual dose increment between dose mantissa changes to within the beginning and ending ripple count increments, which is the maximum possible accuracy within the readout resolution. A procedure has also been developed to correct the data for dead-time effects. This is a simple calculation which can be easily added when necessary. A check of the SAA and maximum polar cap solar particle data shows that the maximum dead-time effect observed thus far is 5%.

All channels are operating properly, although there is some noise added to the dome 4 (and dome 3 in late fall 1985) electron channel (> 10 MeV electrons) count at the higher temperatures on each orbit. The dome 4 detector starts showing noise counts at temperatures above 50°C, while the dome 3 detector shows noise at 55 to 56°C, the maximum observed temperature. The dome 4 (and dome 3) electron flux and dose channels may need correction for this temperature caused background during periods of low ambient fluxes.

A minor problem had shown up in the routine checking for total dose increments. These routines did not check for valid data and were tripped by noise. A detailed check of the false total dose changes showed that the problem was the occurrence of zeroes in the normal SSJ* data stream, and that the Dosimeter was functioning properly. As discussed in Ref. 1.3, Ben Pope had notified Fred Rich of AFGL and Fred Hanser of Panametrics that there had been a minor programming error with the DMSP satellite that resulted in the addition of some zeroes to the SSJ* data stream. The problem occurred with decom at Global Site 3, where the data was stripped out from the telemetry stream. Some of the equipment at site 3 was inadequate and threw out some of the data, leaving zeroes for later processing. This problem occurred from the beginning (November 1983) and was not completely diagnosed until 12 July 1984. The solution required some new equipment for the processing and was corrected by 24 August 1984. It is not certain how extensive the problem was with the earlier data. The processing errors were not consistent and were not noticed until July 1984, when they appeared to be getting worse. The observed zeroes affected only a small amount of data, but require additional checks for total dose increments to avoid generating false increment print-outs for the pre-24 August 1984 Dosimeter data.

A report on the SSJ* calibration and data presentation was prepared with AFGL personnel and published as an AFGL environmental research paper (Ref. 3.1). The proton calibration data from the Harvard Cyclotron were reduced and showed good agreement with the straightforward calculated response. Thus a detailed theoretical analysis of the Dosimeter response to trapped proton fluxes should be accurate, and is presented in Section 5 of Ref. 3.1. The electron calibration data from the RADC Linac were reduced to energy and angular responses, and presented in Section 6 of Ref. 3.1. Analytic fits were provided for the calibrated energy and angular response of all four dome electron channels.

The response of the Dosimeter electron channels to bremsstrahlung from electrons below 1 MeV was calculated approximately and included as Appendix A in Ref. 3.1. The precise bremsstrahlung response is a very complex calculation, so the approach used several approximations to allow a response estimate to be obtained with a reasonable effort. The results show that the bremsstrahlung response for 0.2 to 1 MeV electrons is 4 to 5 orders of magnitude lower than the direct geometric factors.

Some of the Dosimeter data at AFGL have been reduced to flux contour plots over magnetic latitude/longitude coordinates. The proton fluxes show primarily the South Atlantic Anomaly (SAA), while the electron fluxes show the SAA and the north/south low altitude edges of the radiation belts. The star fluxes show the SAA (from high energy proton reactions) as well as the polar caps (from cosmic ray/proton interactions and heavier particles).

3.3 CRRES Dosimeter Fabrication, Calibration and Testing

3.3.1 CRRES Dosimeter Final Design

The CRRES Dosimeter has a modified DC-DC converter to accept the 28 $\pm$ 4 volt bus range, as discussed in Ref. 1.3. The detector sizes, prescalers, and dose compression counters have also been modified to accept the larger expected dose rates (Ref. 1.3), and to provide better dose increment resolution. The final CRRES dosimeter detector and prescale characteristics are given in Table 3.1. The only prescaled proton flux is in channel 4, where the output counts must be multiplied by 8. The prescaler is not reset, so no counts are lost at low flux levels.

The digitizer level calibration for all electron and proton channels is given in Table 3.2, along with the average energy per digitized pulse for a flat energy loss spectrum. The resulting dose channel calibration factors for a flat energy loss spectrum are given in Table 3.3. The calibration factors in Table 3.3 depend on the mass of the sensitive volume of the detectors (Table 3.1), so they would change slightly if a detector must be replaced. The basic method of calculating the K_d constants is given in Section 4.1 of Ref. 2.1.

The 36-bit (of a total 40 bits in the CRRES digital data stream) digital data for one channel readout has the same format as for the DMSP/F7 Dosimeter described in Ref. 2.1. The electron (low linear energy transfer = LOLET) channel fluxes are counted in a 4 x 4 (E x M) bit compression counter, while the proton (high linear energy transfer = HILET) channel fluxes are counted in a 3 x 5 (E x M) bit compression counter. For both, the lowest input count for an 8-bit output of E x M is

$$C_1 = M\ 2^E \tag{3.1}$$

The electron and proton flux compression counter decodings are given in Tables 3.4 and 3.5 using (3.1). The electron flux counter overflows at 524,288 and the proton flux counter overflows at 4096.

Table 3.1

Final CRRES Dosimeter Detector and Prescaler Characteristics

Channel No.	Detector area (cm^2)	Detector thickness (microns)	Detector sensitive mass (g)	Proton flux prescaler	Dose counter prescalers Electron Channel	Proton Channel
1	0.00815	403	7.65×10^{-4}	1	8192	256
2	0.015	434	5.16×10^{-3}	1	8192	1024
3	0.015	399	4.75×10^{-3}	1	8192	512
4	1.000	406	9.45×10^{-2}	8	16384	8192

Table 3.2

CRRES Dosimeter Digitization Energy Levels

	Electrons (keV)					Protons (MeV)				
Level	Average Pulses	Ch 1	Ch 2	Ch 3	Ch 4	Average Pulses	Ch 1	Ch 2	Ch 3	Ch 4
LL(e/p)	0.5	49	51	52	61	1.0	1.02	1.04	1.02	1.04
1	1.5	51	66	59	61	2.0	1.02	1.04	1.02	1.04
2	2.5	125	134	128	111	3.0	1.28	1.26	1.26	1.23
3	3.5	193	217	194	188	4.0	1.91	1.95	1.91	1.87
4	4.5	263	287	263	265	5.0	2.56	2.58	2.55	2.51
5	5.5	336	356	331	344	6.0	3.20	3.23	3.18	3.14
6	6.5	408	434	400	425	7.0	3.84	3.87	3.82	3.77
7	7.5	480	507	467	498	8.0	4.48	4.51	4.45	4.41
8	8.5	549	579	537	578	9.0	5.12	5.13	5.07	5.04
9	9.5	622	655	603	656	10.0	5.74	5.75	5.69	5.66
10	10.5	694	735	674	736	11.0	6.37	6.38	6.31	6.29
11	11.5	765	807	741	809	12.0	7.01	7.02	6.95	6.92
12	12.5	839	885	812	884	13.0	7.67	7.66	7.60	7.57
13	13.5	910	955	883	966	14.0	8.30	8.28	8.23	8.21
14	14.5	979	1035	954	—	15.0	8.94	8.91	8.86	8.86
15	15.5	—	—	—	—	16.0	9.57	9.83	9.59	9.47
e/p(UL)	—	1020	1035	1021	1040	—	10.10	10.21	10.20	10.20
Star thres.							41.2	42.1	41.1	77.5
Avg. energy per pulse*		68.7	72.9	67.2	72.0		0.604	0.607	0.601	0.597

*Calculated for a flat energy loss spectrum.

Table 3.3

Dose Calibration Factors for the CRRES Dosimeter

Dose calibration factors in Rads (Si)/(output dose count)

Channel No.	Electron Kd	Proton Kd
1	1.18×10^{-2}	3.24×10^{-3}
2	1.85×10^{-3}	1.93×10^{-3}
3	1.86×10^{-3}	1.04×10^{-3}
4	2.00×10^{-4}	8.30×10^{-4}

The dose counters use a 4-bit ripple counter (R) and 4 x 4 (E x M) compression counter which counts the output of the ripple counter. The dose count is given by

$$
\begin{aligned}
D &= 16\,n + R + 16\,M\,2^{E}, \qquad E \le 7 \ (E < 8) \\
&\quad 0 \le n \le 2^{E} - 1 \\
&= 16\,n + R + 16\,(M + 8(E-7))128, \quad E > 7 \ (E \ge 8) \\
&\quad 0 \le n \le 127
\end{aligned}
\tag{3.2}
$$

where the break at E = 7/8 reflects the compression counter modification to provide better dose resolution at high total doses. The value of n is the number of ripple counter overflows, and can be obtained from the data stream by counting ripple counter overflows. The compression counter input/output count listing is given in Table 3.6. Note that the entries in Table 3.6 must be multiplied by 16, as in (3.2), in order to be used with the calibration constants in Table 3.3. A dose counter overflow and recycling occurs at 16 x 10,240 = 163840 input counts.

Table 3.4

ELECTRON FLUX COMPRESSION COUNTER

E	M	COUNT
0	0	0
0	1	1
0	2	2
|	|	|
|	|	|
0	14	14
0	15	15
1	8	16
1	9	18
1	10	20
1	11	22
1	12	24
1	13	26
1	14	28
1	15	30
2	8	32
2	9	36
2	10	40
2	11	44
2	12	48
2	13	52
2	14	56
2	15	60
3	8	64
3	9	72
3	10	80
3	11	88
3	12	96
3	13	104
3	14	112
3	15	120
4	8	128
4	9	144
4	10	160
4	11	176
4	12	192
4	13	208
4	14	224
4	15	240
5	8	256
5	9	288
5	10	320
5	11	352
5	12	384
5	13	416
5	14	448
5	15	480
6	8	512
6	9	576
6	10	640
6	11	704
6	12	768
6	13	832
6	14	896
6	15	960
7	8	1,024
7	9	1,152
7	10	1,280
7	11	1,408
7	12	1,536
7	13	1,664
7	14	1,732
7	15	1,920
8	8	2,048
8	9	2,304
8	10	2,560
8	11	2,816
8	12	3,072
8	13	3,328
8	14	3,584
8	15	3,840
9	8	4,096
9	9	4,608
9	10	5,130
9	11	5,632
9	12	6,144
9	13	6,656
9	14	7,168
9	15	7,680
10	8	8,192
10	9	9,216
10	10	10,240
10	11	11,264
10	12	12,288
10	13	13,312
10	14	14,336
10	15	15,360
11	8	16,384
11	9	18,432
11	10	20,480
11	11	22,528
11	12	24,576
11	13	26,624
11	14	28,672
11	15	30,720
12	8	32,768
12	9	36,864
12	10	40,960
12	11	45,056
12	12	49,152
12	13	53,248
12	14	57,644
12	15	61,440
13	8	65,336
13	9	73,728
13	10	81,920
13	11	90,112
13	12	98,304
13	13	106,496
13	14	114,688
13	15	122,880
14	8	131,072
14	9	147,456
14	10	163,840
14	11	180,224
14	12	196,608
14	13	212,992
14	14	229,376
14	15	245,760
15	8	262,144
15	9	294,912
15	10	327,680
15	11	360,448
15	12	393,216
15	13	435,984
15	14	458,352
15	15	491,520
0	0	524,288

Table 3.5

PROTON FLUX COMPRESSION COUNTER

E	M	COUNT
0	0	0
0	1	1
0	2	2
0	3	3
0	4	4
⋮	⋮	⋮
0	31	31
1	16	32
1	17	34
1	18	36
1	19	38
1	20	40
1	21	42
1	22	44
1	23	46
1	24	48
1	25	50
1	26	52
1	27	54
1	28	56
1	29	58
1	30	60
1	31	62
2	16	64
2	17	68
2	18	72
2	19	76
2	20	80
2	21	84
2	22	88
2	23	92
2	24	96
2	25	100
2	26	104
2	27	108
2	28	112
2	29	116
2	30	120
2	31	124
3	16	128
3	17	136
3	18	144
3	19	152
3	20	160
3	21	168
3	22	176
3	23	184
3	24	192
3	25	200
3	26	208
3	27	216
3	28	224
3	29	232
3	30	240
3	31	248
4	16	256
4	17	272
4	18	288
4	19	304
4	20	320
4	21	336
4	22	352
4	23	368
4	24	384
4	25	400
4	26	416
4	27	432
4	28	448
4	29	464
4	30	450
4	31	476
5	16	512
5	17	544
5	18	576
5	19	608
5	20	640
5	21	672
5	22	704
5	23	736
5	24	768
5	25	800
5	26	832
5	27	864
5	28	896
5	29	928
5	30	960
5	31	992
6	16	1,024
6	17	1,088
6	18	1,152
6	19	1,216
6	20	1,280
6	21	1,340
6	22	1,408
6	23	1,472
6	24	1,536
6	25	1,600
6	26	1,664
6	27	1,728
6	28	1,792
6	29	1,856
6	30	1,920
6	31	1,984
7	16	2,048
7	17	2,176
7	18	2,300
7	19	2,432
7	20	2,560
7	21	2,688
7	22	2,816
7	23	2,944
7	24	3,072
7	25	3,200
7	26	3,328
7	27	3,456
7	28	3,584
7	29	3,712
7	30	3,840
7	31	3,968
0	0	4096/0
0	1	1
0	2	2
0	3	3
0	4	4
0	5	5
0	6	6
0	7	7

Table 3.6

DOSE COMPRESSION COUNTERS

E	MA	MB	COUNT
0	0	0	0
0	0	1	1
0	0	2	2
0	0	3	3
0	1	0	4
0	1	1	5
0	1	2	6
0	1	3	7
0	2	0	8
0	2	1	9
0	2	2	10
0	2	3	11
0	3	0	12
0	3	1	13
0	3	2	14
0	3	3	15
1	2	0	16
1	2	1	18
1	2	2	20
1	2	3	22
1	3	0	24
1	3	1	26
1	3	2	28
1	3	3	30
2	2	0	32
2	2	1	36
2	2	2	40
2	2	3	44
2	3	0	48
2	3	1	52
2	3	2	56
2	3	3	60
3	2	0	64
3	2	1	72
3	2	2	80
3	2	3	88
3	3	0	96
3	3	1	104
3	3	2	112
3	3	3	120
4	2	0	128
4	2	1	144
4	2	2	160
4	2	3	176
4	3	0	192

E	MA	MB	COUNT
4	3	1	208
4	3	2	224
4	3	3	240
5	2	0	256
5	2	1	288
5	2	2	320
5	2	3	352
5	3	0	384
5	3	1	416
5	3	2	448
5	3	3	480
6	2	0	512
6	2	1	576
6	2	2	640
6	2	3	704
6	3	0	768.
6	3	1	832
6	3	2	896
6	3	3	960
7	2	0	1,024
7	2	1	1,152
7	2	2	1,280
7	2	3	1,408
7	3	0	1,536
7	3	1	1,664
7	3	2	1,792
7	3	3	1,920
8	2	0	2,048
8	2	1	2,176
8	2	2	2,304
8	2	3	2,432
8	3	0	2,560
8	3	1	2,688
8	3	2	2,816
8	3	3	2,944
9	2	0	3,072
9	2	1	3,200
9	2	2	3,328
9	2	3	3,456
9	3	0	3,584
9	3	1	3,712
9	3	2	3,840
9	3	3	3,968
10	2	0	4,096
10	2	1	4,224

E	MA	MB	COUNT
10	2	2	4,352
10	2	3	4,480
10	3	0	4,608
10	3	1	4,736
10	3	2	4,864
10	3	3	4,992
11	2	0	5,120
11	2	1	5,248
11	2	2	5,376
11	2	3	5,504
11	3	0	5,632
11	3	1	5,760
11	3	2	5,888
11	3	3	6,016
12	2	0	6,144
12	2	1	6,272
12	2	2	6,400
12	2	3	6,528
12	3	0	6,656
12	3	1	6,784
12	3	2	6,912
12	3	3	7,040
13	2	0	7,168
13	2	1	7,296
13	2	2	7,424
13	2	3	7,552
13	3	0	7,680
13	3	1	7,808
13	3	2	7,936
13	3	3	8,064
14	2	0	8,192
14	2	1	8,320
14	2	2	8,448
14	2	3	8,576
14	3	0	8,704
14	3	1	8,832
14	3	2	8,960
14	3	3	9,088
15	2	0	9,216
15	2	1	9,344
15	2	2	9,472
15	2	3	9,600
15	3	0	9,728
15	3	1	9,856
15	3	2	9,984
15	3	3	10,112
0	0	0	10,240
0	0	1	1

3.3.2 CRRES Dosimeter Calibration, Testing and Delivery

The completed CRRES Dosimeter began acceptance testing with the baseline performance test on May 9, 1986. The test sequence of Fig. 6.1 in Ref. 3.2 was used, and the final performance test was on August 6-7, 1986. The Acceptance Data Package was sent to AFGL, BASD, and the Aerospace Corp. on August 12, 1986. The acceptance test had two anomalies. The CE03 RF conducted emissions for power leads were high at 50-300 kHz; and the D3 detector noise level slightly exceeds the lowest threshold at +40^{o}C. These anomalies should not have any significant effects on the Dosimeter or CRRES spacecraft operation. The Dosimeter SN 2 was delivered to AFGL on August 21, 1986, and then hand-carried to BASD. A performance test was made at BASD on August 25, 1986, and verified proper operation of the Dosimeter at delivery to BASD.

The CRRES Dosimeter was calibrated with 0.25-1.75 MeV electrons at the NASA/GSFC Van de Graaf facility during July 7-11, 1986. Only the D1 detector should have a response, and the measured response was consistent with the expected response. More detailed analysis of the calibration data will be performed later. These data will be combined with the higher energy RADC Linear Accelerator calibration data, which are expected to be taken after return of the Dosimeter for storage.

The Dosimeter calibration source background data for both air and vacuum operation are given in Table 3.7. These should be used for performance test comparisons and for background correction to in-orbit data. The delta e dose output count rates are very low because of the large prescalers (Table 3.1) and only upper limits have been measured at this time. The delta e dose count rates will be measured for the Dosimeter before final return to CRRES for launch, which is expected to be at least 2 to 3 years away.

Table 3.7

CRRES Dosimeter Calibration Source Backgrounds

Data in air - average output (TM) counts/sec

Normal Mode					Calibration Mode				
Item	Ch 1	Ch 2	Ch 3	Ch 4	Item	Ch 1	Ch 2	Ch 3	Ch 4
e flux	0.411	0.063	0.061	0.142	L flux	0.92	0.30	0.36	0.66
p flux	2.36	0.51	0.76	0.187*	U flux	1.44	0.19	0.35	0.105*
delta e dose	$<4.2x10^{-4}$	$<4.2x10^{-4}$	$<4.2x10^{-4}$	$<4.2x10^{-4}$	L dose	7.2	3.0	3.6	6.7
delta p dose	$4.6x10^{-2}$	$2.2x10^{-3}$	$7.0x10^{-3}$	$9.0x10^{-4}$	U dose	2.19	0.299	0.55	1.28

Data in vacuum - average output (TM) counts/sec

Normal Mode					Calibration Mode				
Item	Ch 1	Ch 2	Ch 3	Ch 4	Item	Ch 1	Ch 2	Ch 3	Ch 4
e flux	0.42	0.056	0.052	0.116	L flux	0.82	0.28	0.36	0.60
p flux	2.45	0.49	0.79	0.196*	U flux	1.57	0.25	0.45	0.116*
delta e dose	$<4.9x10^{-4}$	$<4.9x10^{-4}$	$<4.9x10^{-4}$	$<4.9x10^{-4}$	L dose	9.1	3.0	4.5	6.2
delta p dose	$4.9x10^{-2}$	$2.3x10^{-3}$	$7.4x10^{-3}$	$9.3x10^{-4}$	U dose	2.4	0.37	0.68	1.46

* Channel 4 p flux (U flux) has a prescale of 8, so the actual detector count rate is 8 times the TM output count rate.

Note: The delta e dose output count rates are very low and only upper limits have been measured thus far.

3.4 CRRES Integration Support

Documentation from BASD relating to CRRES integration and related instrument tests and interfaces have been reviewed and modified as necessary. Final power consumption levels were provided for the Dosimeter (AFGL-701-2) and the Fluxmeter (AFGL-701-4). Various BASD Test Procedures were reviewed and modified as they were received from either BASD or AFGL.

Schematics and wire run lists were provided to BASD and the Aerospace Corporation to enable their verification of the Dosimeter and Fluxmeter interface circuits. Their examination of this information led to a request that one Fluxmeter interface be modified and also revealed discrepancies in three Dosimeter interface circuits (discrepancies between the ICD and schematics). The revised Fluxmeter interface circuit schematic was forwarded to BASD on May 29, 1986 and the three Dosimeter interface circuit discrepancies were addressed in a June 10, 1986 letter to BASD. Copies of these letters were also forwarded to AFGL.

Information requested by BASD concerning on-orbit "initialization" and "normal operating" procedures, for both the Dosimeter and Fluxmeter, was forwarded to AFGL on June 7, 1986. This submission included Red and Yellow limits for all analog monitors, as well as the definition of the bi-level output monitor states.

The Dosimeter and Fluxmeter were hand carried to BASD in late August 1986. Both instruments were given a performance test to verify proper operation at delivery. The Acceptance Data Packages for both instruments were sent to AFGL, BASD, and the Aerospace Corporation on August 12, 1986.

The Dosimeter analog monitor equations for temperature and detector bias voltage are

$$G2T = TM_{cnt} \times 1.741 - 188.0 \quad {}^{o}C \qquad (3.3)$$

$$= TM_{V} \times 87.1 - 188.0 \quad {}^{o}C$$

and

$$G2BIAS = TM_{cnt} \times 2.063 \quad V \qquad (3.4)$$

$$= TM_{V} \times 103.2 \quad V$$

where the BASD test mneumonics are used, and TM_{cnt} is the 8 bit mneumonics telemetry count (0 to 255 range) and TM_V is the telemetry input signal voltage (0.02 V per bit). The red and yellow line limits for the Dosimeter analog monitors are listed in Table 3.8.

The Fluxmeter (AFGL-701-4) has two temperature monitors, one in the sensor given by

$$G4SENT = TM_{cnt} \times 2.605 - 230.8 \quad {}^{o}C \qquad (3.5)$$

$$= TM_{V} \times 130.3 - 230.8 \quad {}^{o}C$$

and one in the DPU given by

$$G4DT = TM_{cnt} \times 2.582 - 251.3 \quad {}^{o}C \qquad (3.6)$$

$$= TM_{V} \times 129.1 - 251.3 \quad {}^{o}C$$

The PMT high voltage is given by

$$G4HV = TM_{cnt} \times 9.812 \quad V \qquad (3.7)$$

$$= TM_{V} \times 490.6 \quad V$$

while the solid state detector bias voltage is given by

$$G4BIAS = TM_{cnt} \times 2.00 \quad V \qquad (3.8)$$

$$= TM_{V} \times 100 \quad V$$

The red and yellow line limits for all of the Fluxmeter analog monitors except the PMT HV monitor are given in Table 3.9, while the PMT HV monitor limits are given in Table 3.10. Note that the PMT HV monitor changes as the PMT HV is commanded to different levels of the 0 to 255 range.

Table 3.8

Dosimeter Analog Monitor Red and Yellow Line Limits

Analog monitor description	BASD mneumonic	Red line limits (TM cnts)	Yellow line limits (TM cnts)
Detector Bias (AM1)	G2BIAS	87/107	92/102
Power Monitor (AM2)	G2PW	105/144	112/137
Temperature Monitor (AM3)	G2T	102/131[a]	108/125[b]

[a] Red line temperature limits are $-10^{\circ}C$ to $+40^{\circ}C$

[b] Yellow line temperature limits are $0^{\circ}C$ to $+30^{\circ}C$

Table 3.9

Fluxmeter Analog Monitor Red and Yellow Line Limits

Analog monitor description	BASD mneumonic	Red line limits (TM cnts)	Yellow line limits (TM cnts)
+10, +5V monitor	G410V	52/63	53/62
+12, -6V monitor	G412V	142/158	143/157
+16V monitor	G416V	184/206	185/205
DPU temperature monitor	G4DT	93/113[a]	97/109[b]
PMT HV monitor	G4HV	107/136[c]	112/130[c]
Sensor temperature monitor	G4SENT	84/104[a]	88/100[b]
SSD bias V monitor	G4BIAS	110/138	120/128

[a] Red line temperature limits are -10°C to +40°C.

[b] Yellow line temperature limits are 0°C to +30°C.

[c] PMT HV monitor varies with HV setting. Listed ranges include all possible HV settings.

Table 3.10

Fluxmeter PMT HV Monitor Values and Limits

Commanded PMT HV level	Monitor value (V-eq. (3.7))	Yellow line limits (TM cnts)[a]
0	1070	107/111
1	1070	107/111
2	1070	107/111
4	1070	107/111
8	1070	107/111
16	1079	108/112
32	1099	110/114
64	1128	113/117
128	1187	119/123
160	1217	122/126
192	1246	125/129
224	1275	128/132
255	1305	131/135

[a] Yellow line limits are for warning. The red line limits of Table 3.9 (107/136) should be used for turn-off condition.

REFERENCES

1.1 P.R. Morel, F.A. Hanser and B. Sellers, "Fabricate, Calibrate and Test a Dosimeter for Integration into the CRRES Satellite," report AFGL-TR-84-0150, (October 1983). Scientific Report No. 1 for Contract No. F19628-82-C-0090. ADA150683.

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